PB-237 750

GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS. VOLUME 12. APPLYING ATMOSPHERIC SIMULATION MODELS TO AIR QUALITY MAINTENANCE AREAS

ENVIRONMENTAL PROTECTION AGENCY

SEPTEMBER 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	PB 237 750
EPA 450/4-74-013		

4. TITLE AND SUBTITLE	5. REPORT DATE
Guidelines for Air Quality Maintenance Planning and Analysis Volume 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas	September 1974 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Source Receptor Analysis Branch Monitoring and Data Analysis Division, OAQPS, EPA Research Triangle Park, North Carolina 27711	10. PROGRAM ELEMENT NO. 2AC129 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A description of the data requirements, spatial and temporal resolution, reliability and applicability to criteria pollutants is presented for three categories of atmospheric simulation models. Categories are distinguished on the basis of their emission inventory requirements. Level 1 requires only an estimate of total emissions in the air quality maintenance area (AQMA). Level 2 apportions total emissions into subareas within the AQMA and expresses the apportioned emissions as emission densities. Level 3 allows explicit treatment of point, line, and area sources of pollution. Several models in each category are described, and their applicability to air quality maintenance programs is discussed.

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

PRICES SUBJECT TO CHANGE

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Atmospheric Models Atmospheric Diffusion Micrometeorology Meteorology	Air Quality Maintenance Air Quality Projection Point Sources Area Sources Line Sources Emission Inventory	13/02

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release Unlimited	None	54
	20. SECURITY CLASS (This page)	22. PRICE
	None	4.25

EPA Form 2220-1 (9-73)

EPA-450/4-74-013
(OAQPS NO. 1.2-031)

GUIDELINES FOR AIR QUALITY MAINTENANCE PLANNING AND ANALYSIS VOLUME 12 : APPLYING ATMOSPHERIC SIMULATION MODELS TO AIR QUALITY MAINTENANCE AREAS

ia

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711
September 1974

OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Air Pollution Technical Information Center, Research Triangle Park, North Carolina 27711; or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

Publication No. EPA-450/4-74-013
(OAQPS Guideline No. 1.2-031)

FOREWORD

This document is the twelfth in a series comprising Guidelines for Air Quality Maintenance Planning and Analysis. The intent of the series is to provide State and local agencies with information and guidance for the preparation of Air Quality Maintenance Plans required under 40 CFR 51. The volumes in this series are:

Volume 1:	Designation of Air Quality Maintenance Areas
Volume 2:	Plan Preparation
Volume 3:	Control Strategies
Volume 4:	Land Use and Transportation Consideration
Volume 5:	Case Studies in Plan Development
Volume 6:	Overview of Air Quality Maintenance Area Analysis
Volume 7:	Projecting County Emissions
Volume 8:	Computer-Assisted Area Source Emissions Gridding Procedure
Volume 9:	Evaluating Indirect Sources
Volume 10:	Reviewing New Stationary Sources
Volume 11:	Air Quality Monitoring and Data Analysis
Volume 12:	Applying Atmospheric Simulation Models to Air Quality Maintenance Areas

Additional volumes may be issued.

All references to 40 CFR Part 51 in this document are to the regulations as amended through July 1974.

NOTE

This guideline is being released in its present form in order to allow its immediate use by State and local agencies. This guideline may be reissued in the near future in order to incorporate comments and suggested improvements offered by the EPA Regional Offices and by State and local agencies and other concerned groups.

VOLUME 12. APPLYING ATMOSPHERIC SIMULATION MODELS TO AIR QUALITY MAINTENANCE AREAS

PREFACE

Volumes 7, 8 and 13 discuss methods which can be used to estimate future county-wide emissions and to allocate these emission projections within a county. Volume 11 presents guidance for locating representative air quality monitoring stations and for interpreting the resulting data. The information contained in this Volume 12 is intended to provide insight into how the emission and air quality information thus obtained might be combined to estimate air quality levels in future years. The vehicle for estimating future air quality is the atmospheric simulation model.

This guideline is not intended as a critical review of atmospheric simulation models, but only as a guide to the types of models, associated data requirements, and levels of detail which are available for use in developing control strategies. Key simulation model parameters and the data needed to estimate these are first identified. Next, three categories of models are distinguished in accordance with the amount and detail of emissions data which are required to use the model. Finally, examples of models from each category are identified and described in terms of their applicability to different pollutants, averaging times, emissions and meteorological data requirements, use, reliability and air quality maintenance analysis.

The models described in this volume are those which are likely to be the most available to air pollution control agencies. Alternate models may be used provided available data are consistent with the model's requirements and the model is appropriate for the pollutant and sampling time being analyzed.

CONTENTS

		Page
I.	Introduction	1
II.	Simulation Model Parameters	2
	A. Pollutant Types and Averaging Times	2
	B. Emission Inventory Requirements	3
	C. Meteorological Data	4a
III.	Types of Simulation Models	6
IV.	Applicability of Models	8
V.	Background Concentrations	11
VI.	Model Validation/Calibration Procedures	11
VII.	Summary	14
VIII.	Caution	14
IX.	Appendix: Model Descriptions	17
	Rollback Model	18
	Appendix J HC-O_x Relationship	21
	Miller-Holzworth Model	23
	Hanna-Gifford Model	25
	HIWAY Model	28
	Air Quality Display Model	31
	Sampled Chronological Input Model	34
	APRAC-1A Model	36
	SAI Photochemical Model	38
X.	References	39
Bibliographical Data Sheet		43

TABLES

Table 1. Summary of Simulation Model Characteristics

Table 2. Models Applicable to Specific Pollutants and Averaging Times

FIGURES

Figure 1. Dispersion Model Flow Diagram

Figure 2. Flow Diagram for the Development of a Control Strategy.

APPLYING ATMOSPHERIC SIMULATION MODELS TO AIR QUALITY MAINTENANCE AREAS

I. INTRODUCTION

The development of an air quality maintenance plan is strongly dependent on an adequate methodology for relating pollutant emissions to ambient air quality. The methodology is required so that conclusions can be reached regarding (1) the effect of anticipated growth in an area on air quality during some specified future period and (2) the ability of selected control strategies to maintain air quality standards throughout this period. The most commonly used tool for relating emissions and air quality is an atmospheric simulation or dispersion model.

An atmospheric simulation model can be defined as a mathematical description of the transport, dispersion and transformation processes that occur in the atmosphere. In its simplest form, such a model relates pollutant concentrations (χ) to pollutant emission rates (Q) and a background concentration (b),

$$\chi = kQ+b \qquad (1)$$

The constant k is a function of atmospheric conditions and the spatial relationship between source and receptor. Atmospheric simulation models are ultimately concerned with the variability of k, and of emission rate and their impact on pollutant concentrations.

This review is intended only as a guide to the types of models, associated data requirements, and levels of detail which are available for use in developing control strategies. It is not intended as a critical review of atmospheric simulation models.

II. SIMULATION MODEL PARAMETERS

The type of simulation model which is used to examine a specific growth situation or maintenance plan depends on a number of parameters. These parameters include the pollutant and averaging times under consideration, the detail of the emissions inventory, and available meteorological data.

A. Pollutant Types and Averaging Times

The types of pollutants that are commonly considered in dispersion model applications are: (1) SO_2 and total suspended particulates (TSP) as pollutants emitted primarily by stationary sources, (2) CO and fine particulate matter such as that emitted from mobile sources, (3) pollutants such as HC and NO_x which are emitted from both stationary and point sources and react in the atmosphere to form oxidants.

For purposes of discussion here, CO and particulate matter are treated as pollutants which do not transform or decay in the atmosphere. However HC and NO_x are involved in numerous chemical reactions in the atmosphere; these reactions can be properly accounted for only by highly sophisticated, complex models. SO_2 is known to decay in the atmosphere and to form other sulfur compounds. However such chemical changes are not well documented. Some models attempt to account for these changes by the use of a half-life term; usually half-life is assumed to be on the order of a few hours. Some models completely ignore such a decay. It should be noted that NO_2, emitted as a pollutant from an isolated point source in a non-reactive atmosphere, may be treated in a manner similar to SO_2; this should be done with great care.

Reproduced from best available copy.

The averaging times for which dispersion models must be used vary with the National Ambient Air Quality Standards applicable to those pollutants. Dispersion models which allow concentration estimates to be made for the following combinations of pollutants and averaging times are needed: SO_2 and particulate matter for 3-hour (SO_2 only), 24-hour and annual averages; CO for one-hour and eight-hour averages; oxidants for one-hour averages; and NO_2 for annual averages. Dispersion models estimate concentrations for a one-hour period or for seasonal or annual averages. If an average concentration for a period of intermediate length (e.g., 3-, 8-, 24-hour is required, two options are available. One, the model can be used to estimate concentrations hour-by-hour for the period under consideration and an average of all hours taken; this is the preferred method. Two, statistical techniques suggested by Larsen[1] for urban areas or empirical techniques suggested by Turner[2] and others for point sources can be used to convert a concentration for one averaging time to a concentration for longer or shorter averaging times.

B. Emissions Inventory Requirements

The detail of the emissions inventory is a determining factor of the dispersion model used to estimate concentrations. Pollutant sources generally can be separated into point sources, line sources and area sources. Point sources are defined as those which have emissions of a pollutant greater than some limit, such as 100 tons per year. Any space heating, process or incineration source which emits this amount of pollutants or more is considered a point source. Line sources are generally confined to roadways and streets along which there are

Reproduced from best available copy.

well defined straight movements of motor vehicles and their emissions. Area sources include the multitude of minor sources with small emissions which are impractical to consider as individual point or line sources. Such area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square. Commonly, emissions from such sources are prorated over areas of one to 100 square kilometers, depending on the available detail of emissions and desired refinement of modelling results. In cases where there are no data on the spatial distribution of emissions, the emissions inventory may be limited to one average emission for the entire area of concern.

For a point source the following minimum data are required as input to a dispersion model: pollutants emitted; average emission rates (some identification of shorter term variations may be desirable); physical stack parameters such as stack height, stack diameter, stack exit velocity and stack exit temperature; and location of the source in appropriate grid coordinates. Desirably, a point source emissions inventory should include these data for all sources with emissions greater than 100 tons per year. However a less precise estimate can be made using only data from larger sources.

Typically for line sources, data are required on the width of the roadway and its center strip, the types and amounts (grams per second per meter) of pollutant emissions, the number of lanes and the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments must be specified in appropriate grid coordinates.

Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated, a representative average stack height for the area sources, the location of the centroid or the southwest corner of the source area in appropriate coordinates. For circumstances where only total area-wide emissions are available, supplementary information on the dimensions of the area are required.

It should be noted that the emissions inventory available for use with most dispersion models is representative of annual average pollutant emissions. A level of specification greater than this is generally not available, simply due to a lack of data. The model used to estimate pollutant concentrations cannot be contingent upon whether or not an hourly emissions inventory is available. In some cases factors which specify the diurnal variations of certain source classes are built into a model. However unless otherwise identified it will be assumed in this review that the same inventory is used to estimate hourly as well as annual average concentrations.

C. Meteorological Data

Meteorological data required to describe transport and dispersion in the atmosphere are wind direction, wind speed, atmospheric stability and mixing height. Wind direction determines the direction

of movement of the plume. Wind speed affects the initial dilution of the pollutant as it is emitted from the stack. The atmospheric stability determines the rate of dilution as the plume moves downwind. Mixing height determines the depth of the atmosphere through which pollutants can be dispersed in the vertical. These parameters are routinely measured by National Weather Service (NWS) stations. They are available both as individual observations and in summarized form from the National Climatic Center in Asheville, North Carolina. Other sources of similar data may be local universities, industrial companies, pollution control agencies and consultants. However, data from these sources are likely to be less comprehensive in scope than that from the NWS. Simple dispersion models require, as a minimum, data on wind speed. The more sophisticated models require much more detailed data on the temporal and spatial variations of the above meteorological parameters.

For a dispersion model to be useful and valid the meteorological data input to the model must be representative of the transport and dispersion conditions which the model is attempting to simulate. The representativeness of the data is dependent on (1) the proximity of the meteorological monitoring site to the area under consideration, (2) the complexity of the terrain in the area, and (3) the immediate surroundings of the monitoring site. The representativeness of the data can be adversely affected by distance between the source areas and receptors of interest, valley-mountain terrain, presence of large bodies of water and urban-rural differences.

The most representative meteorological monitoring site(s) should be selected. For the models to be considered in these guidelines (except for the SAI model) only one representative site is required. However, in an area encompassing widely differing meteorological regimes attention should be given to applying the model with more than one set of meteorological data. Meteorological consultation for the application of models is required in this circumstance, and is highly desirable in any case.

The detail of the emissions and meteorological data will determine which dispersion models can be used to estimate concentrations. For example, given an urban area for which (1) all point/line sources have been identified, (2) all other emissions are accounted for as area sources and (3) all meteorological parameters are available on an hourly basis, specific detailed dispersion models can be used. However, if it is not possible to define the locations and existence of point sources, it becomes necessary to estimate emissions and distribute these as area sources without regard to specific site locations. Thus a dispersion model requiring less detailed emissions data may be necessary. In cases where only the crudest area-wide emissions are available, very elementary models must be used. Obviously, the greater detail with which a model considers spatial and temporal variations in emissions and meteorological conditions, the greater its ability to distinguish between the effects of various air quality control strategies.

III. TYPES OF SIMULATION MODELS

Atmospheric simulation models can be categorized into three general groupings. They are: (1) models requiring only total area-wide emission data, (2) models requiring specific information about point/line and area

sources and (3) models requiring area source emissions allocated on a sub-county basis.

The first category encompasses models which are limited to consideration of only total area-wide emissions. There is no identification of individual point sources or specific area sources. The meteorological input, if required at all, is in terms of very general parameters such as average wind speed and average mixing height. Concentrations estimated with such models are either averages for the whole area or are site specific and apply only where there are air quality data. These models include the Rollback Model;[3] the 40 CFR Part 51, Appendix J HC-O_x Relationship;[4] and the Miller-Holzworth Model.[5] These models have limited usefulness for evaluating individual air quality control strategies. They can only determine the impact of total pollutant emissions on air quality. They cannot consider in any way how those emissions or the resulting air quality levels are spatially distributed across an area.

The second class of models is that which considers in detail point/line source and area source emissions of pollutants. These models have detailed requirements for meteorological inputs and consider complex atmospheric mechanisms for estimating the downwind transport, dispersion and transformation of pollutants. These models can be used to estimate concentrations at any site in an area for which estimates are desired. This type of model includes the Air Quality Display Model[6,8] the Sampled Chronological Input Model[7] and the APRAC-1A Model.[9,10,11] For cases where

there is a lack of detailed point/line source data, the input to these models can be limited to area source emissions, wherein all point source emissions are summed in the area sources. It should be noted that such a summation, should it be necessary, will considerably detract from the reliability of the dispersion models.

The last class of dispersion model is that which considers only area source emissions. This includes the SAI Photochemical Simulation Model[12] and the Hanna-Gifford Model.[13,14] The SAI model is a sophisticated photochemical dispersion model which does not specifically consider point sources. The Hanna-Gifford model is a simplified area source model for stable pollutants. While the latter model does not consider point/line sources, the impact of point or line sources can be individually determined by the application of a point source model[11,15] or a line source model such as HIWAY.[11,16] Both the SAI and the Hanna-Gifford models allow concentrations to be estimated for a receptor in any of the designated source areas; however only one representative air quality value for each area can be determined.

IV. APPLICABILITY OF MODELS

For those areas with very poor information on the spatial distribution of pollutant emissions the application of the first type of simulation model (e.g., Rollback, Appendix J, Miller-Holzworth) is suggested. Where possible the Miller-Holzworth model is preferred for estimating area-wide average concentrations of SO_2 and TSP. Where oxidant concentrations must be estimated, either the Appendix J or rollback

approach may be necessary; these models allow reduction in HC emissions to be determined directly from the required reduction in O_x concentrations. Rollback should be used for estimating CO concentrations in accordance with procedures described in Volume 1.[17]

In those areas where there is detailed information on pollutant emissions (current emissions and projected emissions to 1985), the AQDM, SCIM, APRAC-1A or SAI models may be used, depending on the averaging times and the pollutants to be considered. However, it should be noted that the SCIM and SAI models are currently in a developmental and debugging phase; they are not now available for general distribution as computer programs. In those cases where the pollutant emissions projected to 1985 can only be known on an area-source basis, it is recommended that either the Hanna-Gifford or the AQDM be used with just area sources.

The data requirements, model outputs and general performance of these various models are summarized in Table 1. The summary is structured from the most elementary to the most sophisticated models. In the table, "1's" indicate factors which are the most general or the easiest to work with. Increasing numbers indicate factors which are more detailed or difficult to work with. The Appendix to this guideline (1) examines the models listed in Table 1 in greater detail, (2) discusses the emissions and meteorological requirements to operate these models, and (3) identifies the availability and reliability of these models. For easy reference, Table 2 indicates the models which are applicable to specific pollutants and averaging times. The models are listed according to level of detail and applicability.

Table 1

Summary of Simulation Model Characteristics

Model Name	Pollutant Specification	Averaging Time Specification	Emission Data	Meteorological Data	Concentration Estimates	Ease of Use	Availability	Reliability	Applicability to AQM
Rollback	Any	Any	1	1	3	1	1	3	3
Appendix J	O_x	1 Hour	1	1	3	1	1	3	3
Miller-Holzworth	SO_2,TSP	1 Hour, Annual	1	3	3	1	1	1	3
Hanna-Gifford	SO_2,TSP CO	Annual	1	2	3	1	1	1	3
Hanna-Gifford w. Point Source model	SO_2,TSP	1-24 Hour	2	5	2	2	1	1	2
w. HIWAY	SO_2,TSP CO	1-24 Hour 1-24 Hour	3 3	5 5	1 1	2 2	2 2	1 1	1 1
AQDM	SO_2,TSP	Annual	3	4	1	3	2	1	1
SCIM*	SO_2,TSP	1-24 Hour	3	5	1	3	3	2	1
APRAC-1A	CO	1-24 Hour	3	5	1	3	2	2	1
SAI*	CO,NO_2,O_x	1-10 Hour	2	5	2	3	3	2	2

*These models are currently in a developmental and debugging phase; they are not available for general distribution as computer programs.

Key to Table 1

A. Pollutant Specification

Any pollutant

Specific Pollutants (SO_2, TSP, CO, O_x, NO_2)

B. Averaging-time Specification

Any averaging-time

Annual Average

1 to 24 hour Average

C. Emission Data

1. Area-wide Emissions Total
2. Total emission distributed as finite area sources
3. Detailed point, line and area sources

D. Meteorological Data

1. None
2. Average wind speed
3. Average wind speed and mixing height
4. Frequency distribution of wind direction, wind speed, stability and mixing height
5. Hourly variations of wind direction, wind speed, stability and mixing height

E. Concentration Estimates

1. Estimates at any specified point
2. One estimate for each area source grid
3. One estimate applicable to entire AQMA

F. Ease of Use

1. Slide-rule
2. Small computer effort
3. Major computer effort

G. Availability

1. Open literature
2. National Technical Information Service
3. EPA, upon request

H. Reliability

1. Can be verified and calibrated
2. Verification is incomplete, possibility of calibratic is uncertain
3. Questionable; acceptable for crude estimates only

I. Applicability to AQM

1. Can distinguish between specific source and land use
2. Can distinguish between land use types only
3. Considers no distinction between sources or land use

Table 2

Models* Applicable to Specific Pollutants and Averaging Times

SO_2 and TSP Annual Average	SO_2 and TSP 24-Hour Average	SO_2 and TSP 3-Hour Average
AQDM	SCIM***	SCIM***
Hanna-Gifford	Hanna-Gifford*** with point source model	Hanna-Gifford*** with point source model
Miller-Holzworth	AQDM**	AQDM**
Rollback	Rollback	Miller-Holzworth***
		Rollback

CO 1-and 8-Hour Average	O_x 1-Hour Average	NO_2 Annual Average
APRAC-1A***	SAI	Rollback
Hanna-Gifford*** with HIWAY	Appendix J	
Rollback	Pollback	

* Listed according to level of detail and applicability.

** Statistical conversion of averaging times required.

*** Pepetitious application of model to each hour under consideration is required for averaging times longer than 1-hour.

It should not be construed that the models discussed here are the only ones for relating emissions to air quality. Other models which have been summarized and discussed by Lamb, et al,[18] Calder,[19] Stern,[20] and Moses[21] are available from private consultants and other governmental agencies. Exclusion of these other models from this volume is not meant to imply that they cannot or should not be used. The input and output of these models should be compared with that of the models described herein to determine whether they are being used in an appropriate fashion. The models discussed in this Volume are (1) those most readily available to air pollution control agencies and (2) representative of the state-of-the-art for atmospheric simulation models.

V. BACKGROUND CONCENTRATIONS

It must be noted in the application of these simulation models that background concentrations of pollutants must also be specified. The simulation models estimate concentrations only for pollutants which have identified sources. If pollutants occur naturally in the atmosphere or are the result of unidentified distant pollutant sources, these pollutant concentrations must be accounted for and separately added to the dispersion model estimates. For example it is commonly assumed that the natural background concentration of TSP is 30-40 $\mu g/m^3$ over much of the Eastern United States.[22] It is usually necessary to add a concentration of this magnitude to any concentration estimates for TSP.

VI. MODEL VALIDATION/CALIBRATION PROCEDURES

To be certain that the dispersion model estimates are as accurate as possible, validation-calibration is required. Any model may have faults which cause estimated concentrations to be in error. Therefore,

it is necessary to validate and calibrate the model estimates. The availability and accuracy of the input data to these models will significantly influence the accuracy of the model estimates. The source factors which have the greatest impact on the accuracy of the estimates are the accuracy and completeness of the emissions data, the accuracy and completeness of data for the physical plant parameters, and the exactness with which the location of the sources is determined. The accuracy of the concentration estimates are also affected by the location, exposure, and representativeness of the meteorological monitoring sites and the overall accuracy and completeness of the meteorological data. Similarly, the validation of the dispersion model is affected by the location, exposure, and representativeness of the air quality sampling sites and by the accuracy and completeness of the air quality data itself. These data should be available for the same averaging times as the concentration estimates. For proper validation of the more sophisticated dispersion models, air quality data should describe the spatial variation of pollutant concentration across the area. In short, if the air quality data are in any way unsuitable or incorrect, the validity of the dispersion model estimates cannot be determined. Statistical methods available for validation of models include skill scores, contingency tables, correlation analyses and comparisons of time series and spatial variations.[21]

If evaluation by one or more of these statistical techniques indicates that the concentration estimates are not a satisfactory representation of observed concentrations, even though all source, emissions, meteorological and air quality data are reliable and complete, it must be

assumed that the dispersion model itself is inadequate or inappropriate for the area under consideration. This is likely to occur (1) in areas with complex topographic/meteorological conditions, (2) where model inputs do not allow a complete description of significant source variations, (3) where atmospheric reactions or rates of removal of the pollutant from the atmosphere are not adequately accounted for in the model, or (4) for pollutants which were not considered in development of the model. In such cases it will be necessary to find a more appropriate model or make appropriate changes to available models.

Once the dispersion model estimates have been determined to be acceptable, they must be calibrated. The calibration should account for systematic errors in the estimates. A model is calibrated by comparing the calculated concentration estimates to observed air quality. Then by use of a regression equation or averaged correction factor, a means for adjusting the individual model estimates is developed. It should be emphasized that once a model is calibrated, all future uses of the model must employ a data base which is similar to that on which the calibration was based. For example if AQDM were calibrated for a 1970 point/area source data base, the calibration could then be used to estimate 1985 concentrations with an appropriate emission inventory projected to 1985. However for consistency, the projected inventory should identify all point sources in 1985. If due to a lack of information, the inventory for 1985 must be generalized to area source emissions, then the base year (1970) should consider an emissions inventory which also has been generalized to area source emissions.

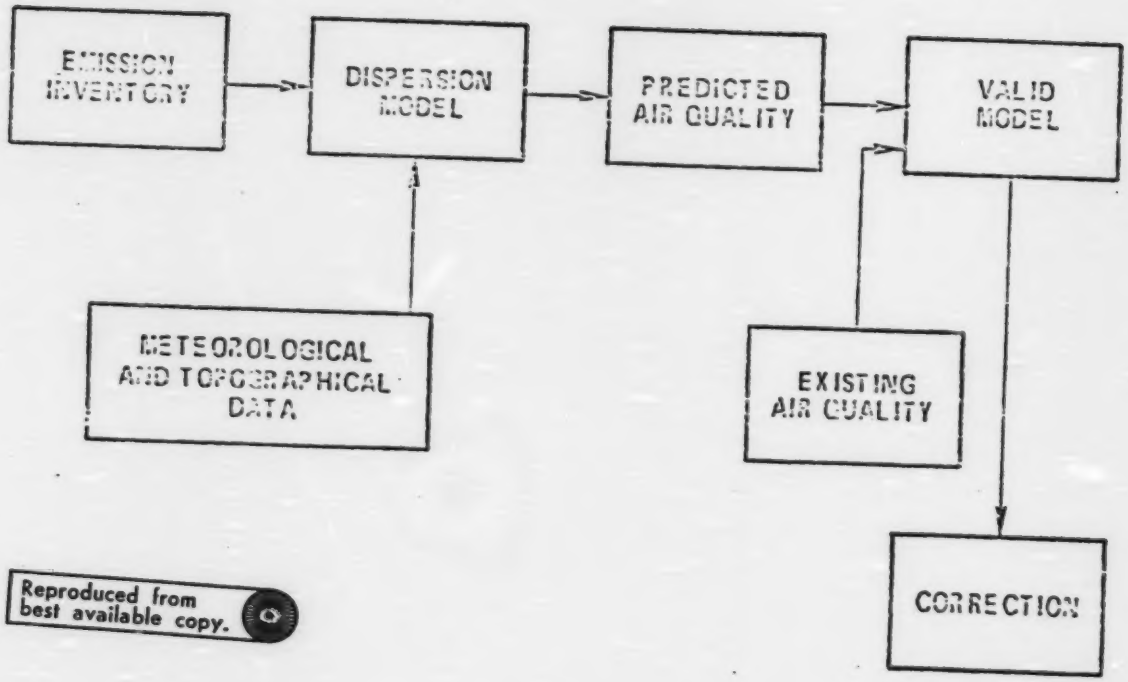
VII. SUMMARY

The use of the above data and dispersion models in air quality maintenance should proceed as follows. First, a base year is selected. The dispersion model is applied to emissions and meteorological data for this base year and the dispersion estimates compared to the observed air quality. In this way the model can be validated and deficiencies in the dispersion model can be identified and corrected (Figure 1). In addition, any inadequacies in the basic emissions inventory, the meteorological data, or available air quality data can be identified. Next, the dispersion model is applied to the projected 1985 emissions inventory. For this application, meteorological data which can be considered representative of atmospheric conditions in 1985 are required. This necessitates the use of climatological means and extremes or the use of data from a year which exhibited average dispersion conditions. With these data the likelihood of exceeding the air quality standards in 1985 can be ascertained. This is done with the calibrated model so that some confidence in the estimates is assured. Next, if it is determined that the air quality is likely to be greater than National Ambient Air Quality Standards in 1985, this dispersion model can be used to determine the ability of alternative strategies for emissions control in 1985 (Figure 2). Thus, the dual purpose of air quality maintenance evaluation can be met.

VIII. CAUTION

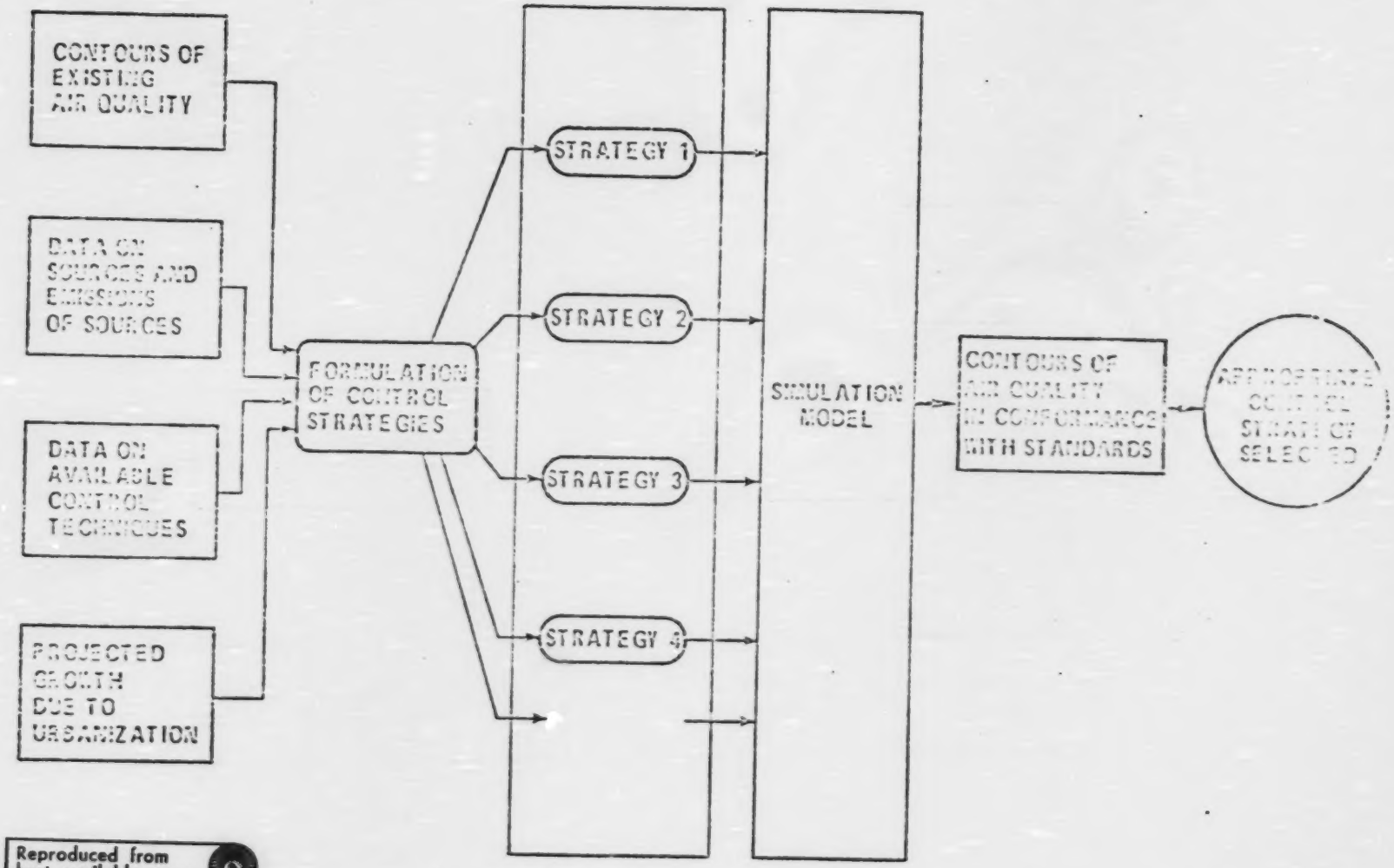
Like any "tool," atmospheric simulation models are useful only if the user understands how to apply them and is aware of their vagaries. They are highly specialized tools which require, in many cases, large

amounts of detailed technical data. As such they should not be used indiscriminately. It is strongly urged that the services of competent air pollution meteorologists, engineers and air quality analysts be solicited in the application of atmospheric simulation models. This need is especially critical in the application of the more sophisticated models and in complex meteorologic/topographic locales. Without the availability of such expertise, a model applied improperly or with incorrect data, can lead to erroneous conclusions about the ability to maintain air quality.



Reproduced from best available copy.

Fig. 1 - Dispersion model flow diagram.


CONTOURS OF EXISTING AIR QUALITY
DATA ON SOURCES AND EMISSIONS OF SOURCES
DATA ON AVAILABLE CONTROL TECHNIQUES
PROJECTED GROWTH DUE TO URBANIZATION
FORMULATION OF CONTROL STRATEGIES
STRATEGY 1
STRATEGY 2
STRATEGY 3
STRATEGY 4
SIMULATION MODEL
CONTOURS OF AIR QUALITY IN CONFORMANCE WITH STANDARDS

Reproduced from best available copy.

Fig. 2 - Flow diagram for the development of a control strategy.

IX. Model Descriptions

ROLLBACK MODEL

The rollback model is based on the simple expression relating pollutant concentrations (X) to pollutant emission rates (Q) and a background concentration (b).

$X = kQ + b.$

The rollback model assumes that the dispersion parameter k does not vary with time or with the source-receptor relationship and that changes in emission rates are uniform across the area. Thus the relationship of emissions (Q_{85}) and air quality in a future year (X_{85}) to the emissions (Q_{base}) and air quality (X_{base}) in a base year can be expressed by the following proportionality:

$$\frac{X_{85}-b}{X_{base}-b} = \frac{Q_{85}}{Q_{Base}}$$

The basic assumption in the model is that a given percent reduction or increase in pollutant emissions will result in a similar reduction or increase in pollutant concentrations. It is simply a tool for scaling concentrations up or down to reflect similar changes in the gross emission rates.

The rollback model is applicable to most pollutants and averaging times for which appropriate data are available. Input to the rollback model requires total area-wide emissions for the base year and for 1985 or other years of interest. A pollutant concentration representative of air quality for the area and the averaging time

of interest is also necessary. It should be noted that since there is no allowance for specifying the dispersion parameter k or other meteorological parameters, this model cannot be used to estimate concentrations at sites where representative air quality data do not exist.

An expansion of the simple rollback procedure is called Modified Rollback.[3] Modified rollback is a technique for considering a range of source categories for the pollutant being considered. It can be expressed as

$$\frac{x_{85} - b}{x_{Base} - b} = \frac{\sum_{i=1}^{N} (Q_i \, G_i \, F_i)_{85}}{\sum_{i=1}^{N} (Q_i)_{Base}},$$

where G is a growth factor, e. g. the ratio of population projected to 1985 versus population in the base year,

F is the emission factor ratio, e.g., the ratio of expected emissions per unit of population in 1985 to emissions per unit of population in the base year,

N is the number of source categories,

i is a particular source category, e.g. light-duty vehicles, stationary sources, etc.

In cases where the area-wide pollutant emissions are contributed by a variety of source types with differing emissions, growth rates and applicable controls, the modified model will allow the situation to be studied in more detail.

The rollback models are applicable anywhere for which there are basic data on area-wide emissions and representative air quality for a particular base year. The simple rollback model can be applied with

simplified hand calculations and is widely used. Modified rollback has been computerized and documented. The programs and associated documentation on the "Motor Vehicle Emission Estimation Program" and the "Modified Rollback Computer Program" has been made available to all EPA Regional Offices.

The rollback models in general are valid for the simplified case of only one type of source uniformly distributed across an area affecting a receptor. Mobile sources and associated CO emissions are an example of the type of source which may approximate this situation. Accuracy is lost as the variability of source types and emission rates increase and the impact of atmospheric processes on pollutant concentrations increase. Thus due to the importance of point sources for TSP and SO_2 and the reactive nature of NO_2 and O_x, this model can provide only very crude estimates of concentrations for these pollutants.

APPENDIX J HC-O_x RELATIONSHIP

Appendix J of 40 CFR Part 51, the Requirements for Preparation, Adoption, and Submittal of Implementation Plans (36 F.R. 15486), is a graphical presentation of the percent reduction in hydrocarbon (HC) emissions required to reduce an observed peak hourly average oxidant (O_x) concentration to the National Ambient Air Quality Standard (NAAQS) for O_x. The relationship assumes that the maximum 1-hour O_x concentration is directly affected by the quantity of HC emitted during the morning hours. This assumption is based on the maximum observed relationship of HC and O_x concentrations for selected cities. This relationship can be used to determine the effect a change in HC emissions will have on peak oxidant concentrations.

To use the Appendix graph it is assumed that HC emissions are uniform across the whole area and that the peak O_x concentration in the area has been identified. Inherent in the use of Appendix J is the assumption that meteorological conditions and the source-receptor relationship are invariant. Thus there is no need for input of meteorological data. Similarly this approach cannot be used to estimate concentrations at sites where air quality data does not exist. It too is simply a means of scaling O_x concentrations to variations in HC emissions. Its application is restricted to peak hourly average O_x concentrations. However it is generally applicable to any area where the formation of O_x is a problem.

As noted above the Appendix J relationship is presented in the Federal Register. Its application is elementary. The reliability of

this relationship for determining the effect of HC emissions on O_x concentrations has not been identified. There is no allowance for the photochemical reactions which take place between HC and NO_x and no consideration of O_x concentrations due to natural sources. Thus any conclusions concerning the HC reduction required to achieve given O_x levels derived from this relationship should be considered as very rough first approximations.

MILLER-HOLZWORTH MODEL

The Miller-Holzworth dispersion model is a step in sophistication above the basic rollback model for estimating pollutant concentrations. In this model the dispersion parameter k is expressed in terms of mixing height, wind speed and the geographical size of the city. The model can be used to estimate a one-hour integrated area-wide average concentration for the area under consideration. It is applicable to relatively stable pollutants such as SO_2 and particulate matter. The model has been calibrated for a wide sample of areas so that annual average concentrations of these pollutants can also be estimated. This model is superior in concept to the rollblack model since it can be used to estimate concentrations for an area where no observed air quality data are available. This is a result of the fact that atmospheric dispersion is accounted for in the model.

The model relates pollutant concentrations to emissions and meteorological conditions through an integration of a Gaussian type dispersion model; the integration is perfo rmed across an urban area. The Miller-Holzworth model is expressed as

$$X/Q = 3.994\ (S/U)^{0.115}$$

where no pollutants have achieved a uniform vertical distribution and as

$$X/Q = 3.613H^{0.130} + \frac{S}{2HU} - \frac{0.088UH^{1.26}}{S}$$

where a uniform vertical distribution has begun to form. The basic input

to this model is the uniform average area emission rate (Q) in units of grams per second per square meter. Mixing height (H), wind speed through the mixing layer (U) and city size (S) (distance across the city for a given direction) are also required to estimate pollutant concentrations (X). A discussion of the dispersion model and appropriate seasonal average mixing heights and wind speeds is given in EPA publication AP-101.[5] This publication also provides median, upper quartile and upper decile (X/Q) values for various city sizes. Thus a range of pollutant concentrations can be estimated for the more restrictive meteorological dispersion conditions. However, neither the emissions inventory used as input nor the output of the dispersion model makes it possible to estimate spatial variations in pollutant concentrations across the area. In this sense, any set of emission control strategies which allow similar total area-wide pollutant emissions will result in the same air quality for the area. No matter how different the strategies are, if the total emissions are the same, then the air quality estimated will be the same with this model.

This is a simple model for which concentration estimates can be made with a slide rule or from the summaries in AP-101. The reliability of the dispersion model when applied to specific areas to estimate 1-hour concentrations has not been determined. However, as noted earlier, the model has been calibrated. Such a calibration is presented in Appendix A[23] to Requirements for Preparation, Adoption and Submittal of Implementation Plans (36 F.R. 15486) for a range of city sizes so that estimates of annual average concentrations can be made.

HANNA-GIFFORD MODEL

The Hanna-Gifford dispersion model is the next step upward in dispersion model sophistication. The Hanna-Gifford model is most readily applicable to stable pollutants such as SO_2, particulates, and CO. It has been used to estimate 1-hour and annual average concentrations of such pollutants. The model can be used to estimate an average concentration for any defined area. This model differs from the previous models in the form of the dispersion constant (k). In the basic Hanna-Gifford model the constant is a function of stability, wind speed and the size and number of area sources. The equation relating concentrations to emissions is

$$X = \left(\frac{2}{\pi}\right)^{1/2} \frac{(\Delta x\ /2)^{1-b}}{a(1-b)\ U} \left[Q_o + \sum_{i=1}^{N} Q_i\ [(2i + 1)^{1-b} - (2i - 1)^{1-b}]\right]$$

where

a, b are empirically determined constants used to specify dispersion, they are functions of the atmospheric stability

ΔX is the size (width) of the area sources,

N is the number of upwind sources,

i is a specific upwind source,

Q_o is the pollutant emissions for the area in which the receptor site is located,

Q_i are the emissions for upwind areas.

The model is applied to each area which encompasses a receptor site. The application is made for the wind direction, wind speed and stability class for each meteorological situation under consideration. All sources upwind of the receptor area are included in determining the pollutant impact. This approach is used to estimate hourly average concentrations for

all situations of interest. If data on diurnal variations in emission rates are available, they can be used with the model. Concentrations for other averaging times can be obtained by estimating concentrations for each hour of the period and averaging the hourly concentrations.

Annual average concentrations can be obtained in a manner similar to that described for AQDM. However Hanna-Gifford have simplified this procedure by substituting a more elementary form of the dispersion equation. For annual average concentrations the model takes the simplified form of $\chi x = \frac{C}{\bar{u}} Q$, where C is a constant dependent on the pollutant, $\bar{u}$ is the annual average wind speed, and Q is the average emission density ($g/sec/m^2$) for the whole area of interest. However this form of the model can only be used to estimate a representative average concentration for the whole area.

In examinations of the reliability of this model, it has been shown that the more detailed formulation provides an accuracy similar to that of much more sophisticated models. Correlations generally varying between .60 and .95 depending on the pollutant, averaging time and area have been found.[14] For the simplified model, from an application to a large number of areas, values of the constant C equal to 225 and 50 respectively for particulates and SO_2 were found. However the standard deviation of the error in concentration estimates obtained when the mean value for the constant is used, has been found to be about 50 $\mu g/m^3$ for TSP. Further analysis has shown that the constant is overly simplistic and that a relationship of $\chi = 52 + 91.7\ Q/u$ provides a better estimate for particulate matter. The use of this relationship in place of an average for C reduces the standard deviation of the error to 10 $\mu g/m^3$. For SO_2 a similar

relationship could not be derived because the variation of the constant C was too random. This reflects the importance of a large point source emissions in determining SO_2 concentrations and indicates that caution should be exercised in the use of a value of 50 for C when considering SO_2.

The model is basically applicable for areas where there is no point source information available so that all emissions are grouped into area source emissions. However, if specific point sources or line sources are known the impact of these sources can be estimated independently through the use of an appropriate model and concentrations added to those caused by area sources. Diurnal variations, where available, in emission rates should be considered in the application of such specific models to point and line sources. Appropriate point source models are discussed in guidelines for Reviewing New Stationary Sources.[15] These models are generally accepted to be accurate within a factor of two. The most basic point source dispersion models are available through the National Technical Information Service.[11] An appropriate line source model is discussed in this Guideline under the HIWAY model.

Discussions of the Hanna-Gifford dispersion model are available from various literature sources.[13,14] The model is simple enough to estimate concentrations with a slide rule and hand tabulations.

HIWAY MODEL

The HIWAY model[16] is a basic line source dispersion model. It is applicable to mobile source pollutant emissions along roadways such as highways and streets and is applicable only to stable pollutant emissions (CO and fine particulate matter) from automotive sources. The model is applicable to estimate one-hour average concentrations of these pollutants. By repetitively simulating each hour in an 8-hour or 24-hour period, 8-hour and 24-hour concentrations of the pollutants of interest can be estimated. In this way concentrations at specified distances downwind from the roadway or line source can be obtained.

The basic formulation for this line source model is

$$\chi = \frac{q_i}{u} \int_A^B \frac{1}{\pi \sigma_y(x)\sigma_z(x)} \exp -1/2 \left(\frac{y}{\sigma_y}\right)^2 \quad dL$$

where χ is the concentration at the receptor

u is wind speed

q_e is the constant line source emission rate

σ_y, σ_z are the standard deviations of the concentration distribution in the crosswind and vertical directions; they are dependent on atmospheric stability and on downwind distance from sources to the receptor

A, B are the endpoints of the line source

L is the length of the line source from point A to the ith element of the line source

y is crosswind distance from source element to the receptor.

The model is applied to each lane of traffic which makes up the line source to estimate the contribution to concentrations at specified downwind distances. Concentrations can be calculated for any specified combination of meteorological conditions.

Basic inputs into this dispersion model are emissions in terms of grams per meter per second for each lane making up the roadway for each hour being considered. Due to the diurnal variations in emission rates of automotive sources, emissions should be appropriately varied with time of day. In addition, the length of roadway, its width, and other physical parameters of the roadway need to be specified. Meteorological inputs into the model are stability class, wind direction and wind speed for the hour of interest. The output of the model is one-hour average concentrations at specified points downwind from the roadway. Concentrations estimated for each hour in a given sequence of hours make it possible to obtain 8-hour and 24-hour concentrations of pollutants. The model is not readily applicable to estimating annual average concentrations.

To determine the impact of line sources, in addition to more generalized area source emissions, the HIWAY model can be used in conjunction with the Hanna-Gifford model. The Hanna-Gifford model is used to determine the impact of all other sources in an area while the HIWAY model is used to determine the impact of specific nearby roadways.

The model is available from the National Technical Information Service.[11] HIWAY has been compared with preliminary data which indicate that this model has an accuracy comparable to that of point source dispersion models.

AIR QUALITY DISPLAY MODEL

The Air Quality Display Model (AQDM) is a long-term average concentration urban dispersion model which is best used to determine the impact of a wide variety of stationary source classes on annual average concentrations of SO_2 and TSP. The model has been widely applied to areas with numerous point and area sources; it has been validated and calibrated for these areas.

The model is based on the standard long-term concentration equation

$$\chi \quad \sum_S \sum_N \left\{ \frac{2\,Q\,f\,(\theta,S,N)}{\sqrt{2\pi}\,\sigma_{zs}\,u_s \left(\frac{2\pi x}{16}\right)} \exp\left[-\frac{1}{2}\left(\frac{H_u}{\sigma_{zs}}\right)^2 \right] \right\}$$

where $f(\theta, S, N)$ is frequency during the period of interest that the wind is from direction θ, for the stability condition S, and the wind speed class N.

σ_z is the vertical dispersion parameter at distance x for stability condition S

u is the representative wind speed for class N

H is the effective stack height for wind speed u.

The model is used to determine the impact of all sources at a given receptor, for a given set of meteorological conditions. It then weights this concentration by the frequency with which that particular set of meteorological conditions occurs and then sums over all

meteorological conditions, thus producing a long-term average concentration. Basic inputs to the model are a comprehensive emissions inventory including both point sources and area sources. Meteorological input is a joint frequency distribution of wind speed (6 classes), wind direction (16 cardinal points), and stability class (Pasquill classes A-F) along with an annual average mixing height. The dispersion model can be used to estimate concentrations at any point downwind that is specified.

When adequate point source information is not available a properly calibrated model could be used with just area source information, that is, all point sources included in area source emissions. However, it must be recognized that the reliability of this model or any model will be adversely affected by such an assumption, namely that all point sources can be considered in the area source emissions.

This model is available from National Technical Information Service[6] and as a computer system. A similar model, called Climatological Dispersion Model, is also available.[8,11] The two models have differences in calculatio techniques, however they require basically the same inputs and have the same type of outputs. A significant difference between the two is that there is a source contribution file produced by ADDM which allows the impact of each individual source on air quality to be obtained. The same sort of output cannot readily be obtained from CDM. It should be noted that the ADDM was originally developed with the Holland plume rise equation for calculating effective stack heights. A change to the computer program is now available for the inclusion of the Briggs' plume

rise equation. This latter equation is preferred, especially for large sources, e.g. power plants.

ADPI can be calibrated using regression analysis techniques. In numerous applications of the model a correlation coefficient of 0.8 or greater has been found to be typical.

Reproduced from best available copy.

SAMPLED CHRONOLOGICAL INPUT MODEL

The Sampled Chronological Input Model (SCIM) is one of several dispersion models[20] which are applicable to both point and area source emissions in urban areas. These models as a class are basically used to estimate hourly average concentrations of SO_2 and particulate matter which are emitted from stationary sources. SCIM specifically determines a frequency distribution of one-hour concentrations. If this model or any other model is to be used to estimate 24-hour concentrations, a series of hourly observations must be used to determine 24 1-hour concentrations. While this model does not specifically estimate 24-hour concentrations, it provides a summary of all estimated hourly concentrations. Thus estimates of concentrations for averaging times longer than 1 hour can be tabulated. Through the use of standard statistical techniques SCIM summarizes the 1-hour estimates as a distribution of concentrations. This model can be used to estimate concentrations at any desired site. The model is based on the standard Gaussian dispersion equation;

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where all terms are as previously defined.

Like the AQDM, SCIM accepts as input, specific parameters on point sources and area sources. Although the model estimates hourly concentrations, the emissions data used are annual averages; there is

no allowance for diurnal variations in emissions. Limited tests with variations in emissions based on time of day did not show a consistent improvement in concentration estimates. The meteorological data required are specific hourly data on wind speed, wind direction, stability class and mixing height. The model does provide the option of estimating concentrations for selected intervals, e.g. every 3 hours to lessen the computational burden. A judiciously selected interval, which insures that estimates for all times of day for a sufficiently long period of time, will not adversely influence the frequency distribution for hourly concentrations. Documentation of this model is in progress.

The reliability of this model has not been widely determined; however, applications to three cities indicates that the frequency distributions of 1-hour concentrations estimated by the dispersion model approximately reproduce the observed frequency distributions.

Reproduced from best available copy.

APRAC-1A MODEL

APRAC-1A is a dispersion model which is applicable only to line and area sources of stable automotive pollutants (CO and particulate matter). The model can be used to determine 1-hour averages of these pollutant concentrations or a frequency distribution of such concentrations. It too can be used to estimate concentrations for other averaging times by averaging a series of hourly estimates. It can be used to estimate concentrations at any desired site.

APRAC-1A is based on a modification of the Gaussian dispersion equation. The basic input to this dispersion model is in terms of individual street segments or line sources. The model takes these segments and determines area source emissions from these line sources; these emissions are combined with other specified area source emissions to indicate total emissions. A method for determining diurnal variations in emissions is included in this model. These area sources are oriented in the upwind direction. A logarithmic spacing of the area sources allows the nearby sources to be considered in greater detail than those farther sources, whose individual contributions tend to be merged during longer travel. Meteorological input to the model is the same as with other dispersion models; wind direction, wind speed, stability class and mixing height on an hourly basis.

This model also incorporates a street effects submodel. This submodel allows the impact of localized emissions and wind circulations

on pollutant concentrations to be determined. It basically takes the form of a box model with slightly different methods for calculating concentrations on opposite sides of the road. This difference is an attempt to reflect the impact of the complex wind circulation which has been identified in street canyons.

The model is available from National Technical Information Service.[9, 10, 11] This dispersion model has been applied to St. Louis and San Jose and estimates compared to observed data; it can be expected to have a reliability similar to that of other dispersion models.

Reproduced from best available copy.

SAI PHOTOCHEMICAL MODEL

The SAI model is a photochemical dispersion model. It not only considers the transport and dispersion of pollutants but also the transformation of HC and NO_x into photochemical oxidant pollutants. It estimates the hourly concentration variations in these pollutants; CO, HC, NO, NO_2 and O_x.

The mathematical formulation for this model is considerably different from that discussed for the other dispersion models. This model uses finite difference techniques over a grid of area sources to solve the classical equations of conservation of mass which include local change, advection, diffusion, photochemical reaction and emission.

The emissions input to this dispersion model is specified as uniform gridded area sources; hourly emission rates and their diurnal variations are specified. Meteorological input are hourly data on the spatial variation of wind direction, wind speed and mixing height. The model is capable of estimating for each hour an average concentration for each area identified as an area source. This model is most applicable when large amounts of data are available for a sophisticated analysis of a region. To this date it has only been applied to areas in California.

This model is one of the better sophisticated photochemical models currently available. The reliability of this model has not been thoroughly examined.

VIII. REFERENCES

(1) Larsen, R. I.; "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards"; Office of Air Programs Publication No. AP-89 (NTIS PB 205277); Office of Technical Information and Publications; U. S. EPA; Research Triangle Park, N. C. 27711; (November 1971).

(2) Turner, D. B.; "Workbook of Atmospheric Dispersion Estimates"; PHS Publication No. 999-AP-26 (NTIS PB 191482); Office of Technical Information and Publications, U. S. EPA; Research Triangle Park, N. C. 27711; (1969).

(3) de Nevers, N. and J. R. Morris, "Rollback Modeling--Basic and Modified"; Paper Number 73-139; Presented at 1973 Annual Air Pollution Control Association Meeting; Chicago, Ill.; (June 1973).

(4) U. S. EPA; "Requirements for Preparation, Adoption, and Submittal of Implementation Plans--Appendix J"; Federal Register 36; No. 158; p. 15502; (August 14, 1971).

(5) Holzworth, G. C.; "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States"; Office of Air Programs Publication No. AP-101 (NTIS PB 207103); Office of Technical Information and Publications; U. S. EPA; Research Triangle Park, N. C. 27711; (January 1972).

(6) TRW Systems Group; "Air Quality Display Model"; Prepared for the National Air Pollution Control Administration under Contract No. PH-22-68-60 (NTIS PB 189194), DHEW, U. S. Public Health Service, Washington, D. C. (November 1949).

Reproduced from best available copy.

(7) Koch, R. C. and G. H. Stadsklev; "A User's Manual for the Sampled Chronological Input Model (SCIM)"; GEOMET Report No. E-261 prepared for U. S. EPA Under Contract Number 68-02-0281; U. S. EPA, OAQPS, Research Triangle Park, N. C. 27711; (August 1973) (available in draft form only).

(8) Busse, A. D., and J. P. Zimmerman; "User's Guide for the Climatological Dispersion Model"; Environmental Monitoring Series EPA-R4-73-024 (NTIS PB 227346AS) NERC, EPA, Research Triangle Park, N. C. 27711 (December 1973).

(9) Ludwig, F. L. and P. L. Mancuso; "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program," Prepared for U. S. EPA Division of Meteorology Under Contract CAPA-3-68 (1-69) (NTIS PB 213091); U. S. EPA, Research Triangle Park, N. C. 27711; (September 1972).

(10) Ludwig, F. L. and W. F. Dabberdt; "Evaluation of the APRAC-1A Urban Diffusion Model for Carbon Monoxide"; Prepared for U. S. EPA, Division of Meteorology Under Contract CAPA-3-68 (1-69) (NTIS PB 210819); U. S. EPA, Research Triangle Park, N. C. 27711 (February 1972).

(11) U. S. EPA; User's Network for Applied Modeling of Air Pollution (UNAMAP); (Computer Programs on Tape for Point Source Models, HIWAY, Climatological Dispersion Model and APRAC-1A) NTIS PB 229771 National Technical Information Service, Springfield, Virginia 22151 (1974).

(12) Systems Applications Inc.; Urban Air Shed Photochemical Simulation Model Study--Volumes I-III"; Prepared for U. S. EPA, CRD Under Contract Number 68-02-0339; EPA-R4-73-030a; Washington, D. C. 20460; (July 1973). (Available from APTIC)..

(13) Hanna, S. R.; "A Simple Method of Calculating Dispersion from Urban Area Sources"; J. Air Pollution Control Ass'n., Vol. 21, No. 12, pp. 774-777; (December 1971).

(14) Gifford, F. A., and S. R. Hanna; "Modeling Urban Air Pollution"; Atmospheric Environment, Vol. 7, pp. 131-136; (1973).

(15) U. S. EPA, OAQPS; "Reviewing New Stationary Sources"; Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10; OAQPS No. 1.2-029; (September 1974).

(16) Zimmerman, J. R. and R. S. Thompson; "User's Guide for HIWAY: A Highway Air Pollution Model"; Environmental Monitoring Series EPA-650/4-C08, NERC, EPA, Research Triangle Park, N. C. 27711 (in preparation).

(17) U. S. EPA, OAQPS, CPDD; "Guidelines for Designation of Air Quality Maintenance Areas"; OAQPS Publication No. 1.2-016; U. S. EPA, OAQPS, Research Triangle Park, N. C. 27711; (January 1974).

(18) Lamb, D. V., et al; "A Critical Review of Mathematical Diffusion Modeling Techniques for Air Quality with Relation to Motor Vehicle Transportation"; A Study Prepared for the Washington State Highway Commission, Department of Highways; University of Washington, Seattle, Washington (June 1973).

Reproduced from best available copy.

(19) Calder, K. L.; "Mathematical Modeling of Air Quality Through Calculation of Atmospheric Transport and Diffusion" in Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling, CCMS/NATO, Paris, France (October 2-3, 1972).

(20) Stern, A. C., "Proceedings of Symposium on Multiple-Source Urban Diffusion Models"; Air Pollution Control Office Publication No. AP-86 (NTIS PB 198400), Office of Technical Information and Publications; U.S. EPA; Research Triangle Park, N. C. 27711; (1970).

(21) Moses, H.; "Mathematical Urban Air Pollution Model"; Argonne National Laboratory Report ANL/ES-RPY-001; Argonne National Laboratory, Argonne, Illinois, 60439 (April 1969) (Limited Distribution Only).

(22) McCormick, R. A.; "Air Pollution Climatology in Air Pollution Volume 1, Edited by A. C. Stern, Academic Press, New York, New York 10003 (1968).

(23) U.S. EPA; "Requirements for Preparation, Adoption and Submittal of Implementation Plans--Appendix A"; Federal Register, 36, No. 158; pp. 15494-15495; (August 14, 1971).